Chapter 2

Decision Aid Models and Systems for Humanitarian Logistics. A Survey

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The number and impact of disasters seems to be increasing in the last decades, and their consequences have to be managed in the best possible way. This paper introduces the main concepts used in emergency and disaster management, and presents a literature review on the decision aid models and systems applied to humanitarian logistics in this context.

2.1 Introduction

The number and impact of disasters seems to be increasing in the last decades, and their consequences have to be managed in the best possible way. Recent years have seen an explosion of literature regarding disaster and emergency management, as it is a topic of high relevance in today's world. Among this literature, there is an increasing amount of research regarding mathematical models and systems which can help in the decision aid processes developed when trying to respond to the consequences of a disaster. In this introductory section the main definitions concerning disasters, emergencies and humanitarian logistics are stated, which will allow to classify the research into the main phases of disaster management.

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2.1.1 *Hazards and disasters*

A **hazard** is a threatening event or probability of occurrence of a potentially damaging phenomenon within a given time period and area. It can be both natural or human-made.

- Natural: naturally occurring physical phenomena caused either by rapid or slow onset events which can be geophysical, hydrological, climatological, meteorological or biological (earthquakes, landslides, tsunamis, volcanic activity, avalanches, floods, extreme temperatures, droughts, wildfires, cyclones, storm/wave surges, disease epidemics, animal plagues, etc.).
- Human-made or technological: events caused by humans and which occur in (or close to) human settlements, such as complex emergencies/conflicts, famine, displaced populations, industrial accidents (toxic dumps or radioactive escapes), catastrophic transport accidents, etc.

An **emergency** is a situation that poses an immediate risk to health, life, property or environment.

A **disaster** is the disruption of the normal functioning of a system or community, which causes a strong impact on people, structures and environment, and goes beyond the local capacity of response. Sometimes, to declare or not an emergency as a disaster is a political decision, because it has consequences for the involvement of third parties in the intervention or for insurance, for example.

Catastrophe is another term used in disaster management. There is also a discussion in the literature about the difference between disaster and catastrophe. Usually a catastrophe is considered an extremely large-scale disaster. As stated in Quarantelli [74], *just as "disasters" are qualitatively different from everyday community emergencies, so are "catastrophes" a qualitative jump over "disasters"*. This qualitative jump is reflected in several characteristics and results in important differences in the logistics of the intervention, as discussed in what follows.

2.1.2 *Disaster management and humanitarian logistics*

Disaster response is a complex process that involves severe time pressure, high uncertainty and many stakeholders. It also involves several autonomous agencies to collaboratively mitigate, prepare, respond, and recover from heterogeneous and dynamic sets of hazards to society.

The agents involved differ depending on the type of disaster (civil protection and local security agencies usually manage technological disasters, while natural disasters normally involve also NGOs and international agencies), the disaster consequences and the place where it strikes, due to vulnerability.

The agents involved in disaster response can be classified into three levels, as involvement in the operations depends on the consequences:

- Local level: the first response level, usually addressed by local agencies, civil society organizations and civil protection. Typically, this level of emergency is not declared as a disaster.
- National level: the army and national civil protection, governmental organizations and NGOs are usually involved when an emergency is defined as a disaster. Sometimes, international organizations with local offices also participate at this level.
- International level: foreign governments and inter-governmental organizations, international NGOs for disaster response and the United Nations Agencies. Coordination at this level is a crucial matter, usually performed by OCHA (Office for the Coordination of Humanitarian Affairs) of United Nations, and the IASC (Inter-Agency Standing Committee), primary mechanism for inter-agency coordination, including key UN and non-UN humanitarian partners. This level is reached when national capacity of response is not enough (due to the scale of the disaster and/or the vulnerability of the country) and the national government authorizes an international humanitarian operation.

The decision making processes in disaster management are thus extremely difficult, due to the multiple actors (decision-makers) which are involved, and the complexity of the tasks addressed. Among those tasks, all the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiary's requirements and alleviate the suffering of vulnerable people is called **humanitarian logistics**, as defined in the Humanitarian Logistics Conference, 2004 (Fritz Institute).

Based on this definition, humanitarian logistics also appears in contexts different from disaster management; the World Food Programme (WFP) and the World Health Organization (WHO), for instance, develop many operations which can be considered humanitarian logistics without being a response to a specific disaster. However, it is in disaster management where the application of humanitarian logistics is more complex and difficult and where more differences with business logistics appear. Therefore, our review is restricted to this context. The main issues that differentiate humanitarian supply chains in the context of disaster management from business supply chains are the following:

- Unpredictable demand in terms of timing, geographic location, type and quantity of commodity.
- Short lead time and suddenness of demand for large amounts of a wide variety of products and services.
- Lack of initial resources in terms of supply, human resources, technology, capacity and funding (see Balcik and Beamon [9]).
- Presence of multiple decision makers that can be sometimes difficult to identify.

2.1.3 *Phases, tasks and decisions of the disaster management cycle*

In the decision making processes needed in humanitarian logistics for disaster management, the context and the nature of the decisions to be made change over time as we move from before to after the disaster event. Deciding about preventive actions to mitigate the effects of a possible future earthquake is not the same as deciding about the precise actions to undertake just after it strikes, or a month later. The context-related uncertainties and time pressure may vary a lot from one situation to the other, as well as the nature of the decisions and the criteria of the involved actors. This has led to distinguishing four successive phases in the management of emergencies and disasters according to the main nature of the tasks to be performed and their temporal location with respect to the disaster event:

- Mitigation: all the middle and long-term actions and decisions aimed to prevent and mitigate the consequences of a future disaster, as long as it is not (known to be) imminent. Typical tasks of this phase are the identification of risk groups and vulnerability patterns and their treatment, or the development of prediction systems and emergency plans and the allocation of resources for them.
- Preparedness: all the short-term interventions once the available prediction systems have raised an alarm of an upcoming adverse phenomenon until it finally strikes. This includes setting off the emergency systems and evacuation plans, the real-time tracking of the hazard, the analysis of the most probable scenarios, the reinforcement of critical infrastructures, etc. This phase also includes some long-term decisions such as inventory prepositioning and network design.

- Response: this phase is focused on saving lives and it is characterized by a short duration with high emergency and high uncertainty. It is usually divided into a first response phase, devoted to the rescue and urgent medical assistance of injured and affected people (depending on the disaster scenario, it may last around one week from the moment of the disaster event), and a middle-term response phase, devoted to estimate and mitigate the potentially unattended first needs of the affected population as a result of possible damage to life-line infrastructures and resources (shelter, ordinary medical assistance, water and food supply, etc.). This middle-term stage usually involves the delivery of aid from outside of the affected zone and can last for weeks or even months from the moment of the disaster, depending on its nature and magnitude as well as on the economic and development circumstances of the affected country.
- Recovery: this phase is focused on achieving efficiency and it is characterized by its long duration with low emergency and low uncertainty. It refers to all the long-term actions and decisions aimed to recuperate the normal functioning of the affected community and the reconstruction of the social fabric, including life-line resources, services and infrastructure, and the necessary improvements in order not to repeat the specific vulnerabilities shown by the affected groups and places. Sometimes, after certain disasters, a periodic flow of humanitarian aid will be needed to support particularly vulnerable people, which is outside the scope of disaster management.

Though this division in phases is clear and well-founded from a temporal and conceptual point of view, it is important to remark that the process of disaster management has to be understood as a whole, where phases are not independent of each other despite their different focus. In this way, the preparedness phase relies critically on the prediction systems set up in the mitigation phase and the urgent decision-making of the former phase would be impossible without the previous vulnerability analysis and emergency plans developed in the latter phase. Similarly, the allocation of resources for first response operations must be taken into account when designing the mitigation policy. Besides, the middle-term response stage cannot be successful if it does not enable an adequate recovery process. In this sense the delivery of external aid has to be carefully examined and carried out in order not to destroy the local economy. Furthermore, notice that the recovery and mitigation tasks partially overlap, in such a way that once an affected community has reached a new equilibrium, it has to re-evaluate the possible occurrence of future disasters and thus a new mitigation stage follows the recovery phase. Thus, the disaster management process is a non-stop cycle (see Fig. 2.1, as in Tomasini and van Wassenhove [87]), in which each phase is based on the previous ones, clearly showing the interdependence between all of them.

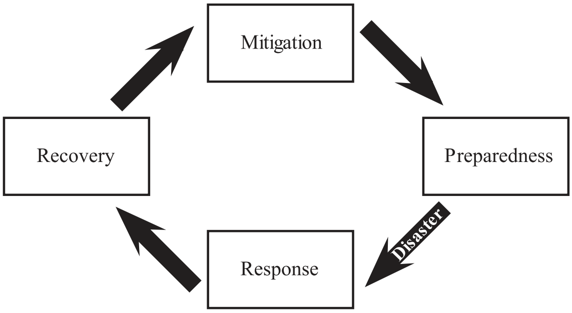

Fig. 2.1 Phases of the disaster management cycle

Some other factors appear that must be considered in all phases of the disaster management cycle. A key factor in humanitarian logistics is the management of funding and donations. Donations are usually classified into two groups: earmarked donations, given by donors to be used in specific operations, and non-earmarked donations, that have no constraints of use. The management of both kinds of donations is crucial to achieve efficiency, and thus it is important to take them into account when making decisions.

In order to help in the decision making processes arising in each of the interrelated previous phases, different mathematical models can be developed. In Altay and Green [4], the literature in Operations Research models for disaster operations management up to 2005 is reviewed. In this work we present an up-to-date review of the Operations Research literature, which is completed with a review on the decision aid systems already in use by different organizations.

The paper is organized as follows. In Section 2.2 the literature on decision aid models is reviewed, classifying the bibliography according to the type of problem, the disaster management phase and the solution technique. Section 2.3 introduces the decision aid systems most commonly used in practice, describing their main functionalities and providing related references. Finally in Section 2.4 some conclusions are drawn.

2.2 Decision Aid Models. Literature Review

This section is a humanitarian logistics literature review focused on papers presenting mathematical models. They will first be classified according to the disaster management phase considered and afterwards according to the type of problem approached. A special subsection will be devoted to donations and funding. At the end of the section a brief classification according to the solution technique used to solve the proposed models is also provided.

We will restrict the review mostly to deterministic solution techniques, because, even though uncertainty is a key factor in humanitarian logistics, the treatment of this uncertainty in the literature is presented in a different chapter of this book.

2.2.1 *Pre-disaster actions: mitigation and preparedness*

In this section, the bibliography concerning mitigation and preparedness has been classified into the following six groups, according to the main problem tackled: assessment, facility location, supply chain design, distribution planning, evacuation, and inventory planning.

Assessment

- Tovia [88] builds a simulation model for emergency response to be used by offices of emergency preparedness. It is conceived to evaluate response capabilities and assess the logistics resources required to evacuate, shelter and protect the population, in a timely fashion in the event of a hurricane.
- Zobel and Khansa [100] present a multi-criteria approach providing a quantitative measure of resilience in the presence of multiple related disaster events, in order to be able to compare several configurations and to assess their relative returns and risks for effective emergency management.
- Kung *et al.* [49] make use of multiple linear regression, multivariate analysis, back-propagation networks and simulation for designing a real-time mobile system to predict and assess the occurrence of debris flows.
- Uchida [91] develops a simulation model for clarifying how disaster warning issuance conditions affect "cry wolf syndrome" in the case of landslides caused by heavy rainfall.

Facility location

- Akkihal [3] considers a battery of mixed-integer linear programs for locating warehouses for non-consumable inventories required for the initial deployment of aid after a disaster occurrence.
- Doerner *et al.* [32] provide a multi-criteria programming model for locating public facilities as schools in areas close to the coast, taking into account risks of inundation by tsunamis. It performs a comparison between two solution approaches: a genetic algorithm and a decomposition technique.
- Eiselt and Marianov [33] propose a 0-1 linear programming model for locating or strengthening cell phone towers in order to maximize service coverage and minimize the loss of communications in case a natural disaster occurs.

Supply chain design

- Hale and Moberg [38] consider a set cover location model for establishing an efficient network of secure storage facilities that can effectively support multiple supply chain facilities.
- Van Wassenhove [93] shows the complexities of managing supply chains in humanitarian settings and outlines strategies for better preparedness.
- Nagurney *et al.* [62] state a variational inequality problem for designing a supply chain network for critical needs, minimizing the total cost and considering demand uncertainty.

Distribution planning

- Nolz *et al.* [66] provide a multi-criteria metaheuristic based on evolutionary concepts for planning water distribution tours in disaster relief, determining the physical location of water tanks and selecting roads to be used for the transportation of drinking water.
- Rottkemper *et al.* [76] propose a bi-objective mixed-integer programming model for integrated relocation and distribution planning of relief items to the affected regions in the aftermath of a disaster.

Evacuation

- Saadatseresht *et al.* [77] propose a three-step approach based on the use of multi-criteria evolutionary algorithms and on a geographical information system to determine the distribution of evacuees into safe areas in an emergency situation.
- Bretschneider and Kimms [16] present a two-stage heuristic approach for a pattern-based mixed integer dynamic network flow model to restructure the traffic routing for evacuating an urban area affected by a disaster.

Inventory planning

- Lodree and Taskin [53] introduce some variants in the classic newsvendor model in order to deal with demand uncertainty in an emergency response inventory planning problem that is relevant to manufacturing, service, not-for-profit, and government organizations that provide supplies, equipment, and manpower to support disaster relief operations.
- Qin *et al.* [73] propose an inter-temporal integrated single-period inventory model to determine the optimal order quantity of emergency resources in a flood incident. It also describes a genetic algorithm based simulation approach.

2.2.2 *Disaster response*

Most of the papers dealing with the disaster response phase are related to the distribution of humanitarian aid, in a global or a local context, the evacuation of people affected by a disaster or the location of support centers. In this section, the bibliography is classified into the following four groups, according to the main problem tackled: last mile distribution, evacuation, large scale distribution, and other problems.

Last mile distribution

- Tzeng *et al.* [90] use fuzzy multi-objective linear programming technics to approach a multi-period aid distribution problem minimizing total cost and total travel time and maximizing minimal satisfaction during the planning period.
- Balcik and Beamon [9] consider a two-phase multi-period planning model for relief distribution. In the first phase, the possible routes for vehicles within the time horizon are generated. In the second phase, the optimal routes and the amount of supplies to

be transported are selected for the coming periods by solving the underlying integer programming problem.

- Campbell *et al.* [18] introduce and analyze two alternative objective functions for the traveling salesman problem and the vehicle routing problem, considering arrival times to destinations, in order to suit the humanitarian nature of the distribution. The new problems are solved with an insertion and local search based heuristic approach.
- Gibbons and Samaddar [37] develop a simulation model for a problem of distribution of vaccines in a pandemic situation and in a context of strong randomness.
- Blecken *et al.* [15] apply both exact and heuristic techniques to deal with a warehouse provision and relief aid flow problem minimizing total cost.
- Nolz *et al.* [65] present a hybrid solution approach based on genetic algorithms, variable neighborhood search and path relinking to tackle a multi-criteria problem of water distribution to the population affected by a catastrophe.
- Vitoriano *et al.* [96] propose a multi-criteria double-flow model to address the problem of distribution of goods to the affected population of a disaster. Criteria such as cost, time of response, distribution equity, security and reliability are considered jointly using a goal programming approach. Some preliminary results are also presented in Vitoriano *et al.* [95] and Ortuño *et al.* [70].
- Berkoune *et al.* [13] develop a genetic algorithm for solving a multi-commodity and multi-depot routing problem which aims to minimize the total duration of all trips.
- Huang *et al.* [42] propose three objective functions for a routing problem concerning cost, speed and equity of the delivery. The three resulting problems are solved with different GRASP based metaheuristics and the objective function values are compared.

Evacuation

- Kongsomsaksaku *et al.* [48] provide a flood evacuation planning model in two levels: shelter location by the authority and shelter selection and evacuation routing by the evacuees. The bi-level programming problem is solved using a genetic algorithm.
- Chiu and Zheng [26] present an evacuation and support planning model on a transport network for real-time emergency response in no-notice disasters. The linear programming model is solved through the matrix formulation.
- Yi and Özdamar [99] describe an integrated location-distribution-evacuation network flow model for coordinating logistic support operations. The model determines the

number of vehicles, the number of wounded people and the amount of commodities traversing each arc via linear programming. Then, loads are distributed among vehicles by solving a system of linear equations. Yi and Kumar [98] use ant colony optimization to solve this problem, but disregarding facility location issues.

- Jotshi *et al.* [44] propose a simulation model with the support of data fusion for an emergency problem of picking up and delivering patients to hospitals.
- Ben-Tal *et al.* [12] apply robust optimization for a multi-period transportation problem consisting of dynamically assigning emergency response and evacuation traffic flow with time dependent uncertainty on the demands.

Large scale distribution

- Angelis *et al.* [6] consider an integer linear programming model to solve a multi-period weekly planning problem of aircraft routing to delivery food to Angola, in the context of the United Nations World Food Program.
- Sheu [80] presents a dynamic aid plan to be used after an earthquake for several purposes: grouping areas, estimation of affected people at each area, estimation of priorities and distribution of aid. Different mathematical techniques are applied, such as fuzzy clustering and multi-objective dynamic programming.
- Adıvar and Mert [1] propose a fuzzy linear programming model to design a plan for transporting international aid from donor countries to the country in need.
- Charles [22] states a global multilevel facility location and distribution model. This mixed integer programming model includes international suppliers, potential warehouses, affected areas and two types of means of transportation: boats and planes.

Other problems

- Beamon and Kotleba [11] introduce a multi-supplier inventory model with discrete random demands and two types of orders: normal and emergency orders. Beamon and Kotleba [10] develop and test three different inventory management strategies for the previous model that are applied in the context of the emergency situation associated to the civil war in South Sudan.
- Jin and Ekşioğlu [43] present an integer programming model for determining alternative routes after a disaster in a road network. An algorithm is proposed to update the

parameters of the simplified linear program and it is tested using a simulated disaster scenario.

2.2.3 *Disaster recovery*

In this section, the bibliography concerning the recovery stage has been classified into the following seven groups, according to the activities involved: civil infrastructure systems, power system restoration, recovery planning, economic recovery, health care and mental health recovery, urban disaster and housing recovery, and other activities.

Civil infrastructure systems: transportation networks, bridges, etc.

- Karlaftis *et al.* [47] present a methodology for optimally allocating funds for repairing an urban infrastructure transportation network following natural disasters using a three-stage genetic algorithm based approach.
- Permann [72] applies genetic algorithms to the problem of infrastructure networks modeling and analysis in order to determine the optimum assets to restore or protect from attack or other disaster.
- Mehlhorn [60] develop a method for prioritizing highway routes for reconstruction after a natural disaster.
- Natarajarathinam *et al.* [63] review the management of supply chains in times of crisis, including the recovery phase.
- Orabi *et al.* [68] present a model for damaged transportation networks to allocate limited reconstruction resources to competing recovery projects, generating optimal trade-offs between minimizing the reconstruction duration and cost. In Orabi *et al.* [69] the post–disaster recovery efforts of damaged civil infrastructure systems are optimized, minimizing both the performance loss of the damaged transportation network and the reconstruction costs.
- Matisziw *et al.* [56] present a multi-objective model to ensure that network restoration during disaster recovery is prioritized so that system performance is optimized.
- Solano [81] works on preparedness, response, and recovery plans, selecting infrastructures for protection in presence of scarce resources.
- Van Hentenryck *et al.* [92] formalize the specification of the single commodity allocation problem for disaster recovery and introduce a novel multi-stage hybrid-optimization algorithm.

- Maya and Sörensen [57] describe how to allocate scarce resources to repair a rural road network after it has been damaged by a natural or man-made disaster.
- Mehlhorn *et al.* [59] present a plan for bridges' repair to restore a highway network that allows accessibility to key facilities in the damaged area.
- Losada *et al.* [54] incorporate the facility recovery time in a model that identifies the optimal allocation of protection resources in an uncapacitated median network to hedge against worst–case facility losses.

Power system restoration

- Crowther and Haimes [30] evaluate risk management options against multiple objectives. This case study calculates an efficient frontier of solutions by integrating a simplified model of the costs of recovery to the power sector derived from open-source data with the Inoperability-Output Model.
- Ang [5] describes a model to plan the recovery of an electrical power transmission grid that has been damaged by a natural disaster or terrorist attack.
- Xu *et al.* [97] determine how to schedule inspection, damage assessment, and repair tasks so as to optimize the post-earthquake restoration of the electric power system.
- Coffrin *et al.* [28] model and solve the power system restoration planning problem for disaster recovery.
- Coffrin *et al.* [29] present a model to decide how to store power system components throughout a populated area to maximize the amount of power served after disaster restoration.

Recovery planning

- Aftanas [2] develops an objective and repeatable process for optimizing the project prioritization phase of the recovery effort.
- Buzna *et al.* [17] consider structures and organization in complex systems. The effectiveness of recovery strategies is studied for a dynamic model of failure spreading in networks.
- Nelson *et al.* [64] build a high level event and role based mobility model for simulating disaster recovery networks.

- Chen *et al.* [23] propose a quantitative measurement to recoverability assessment, and establish a model of recoverability process to minimize the recovery time and optimize the allocation of resources.
- Balasubramanian *et al.* [8] implement an integrated disaster recovery plan based upon a plurality of requirements for an application by receiving a first set of inputs identifying one or more entity types for which the plan is to be formulated.

Economic recovery: small business, private enterprises, insurance, . . .

- Ghesquiere and Mahul [36] discuss the optimal level of sovereign insurance in the case of developing countries.
- Rose [75] examines the consistency of the operational definitions of economic resilience in relation to antecedents from several disciplines, and evaluates the effectiveness of economic resilience to reduce losses from disasters on the basis of recent empirical studies.
- Saleem *et al.* [78] propose a model for pre-disaster preparation and post-disaster business continuity–rapid recovery. The model is used to design and develop a web based prototype of their business continuity information network system facilitating collaboration among local, state, federal agencies and the business community for rapid disaster recovery.
- Luckey [55] presents a literature review from 2001 to 2008, which identifies key stages for consideration when performing information technology disaster recovery planning to ensure business viability if disasters occur.

Health care and mental health recovery

- de Mel *et al.* [31] measure mental health recovery and economic recovery for small business owners affected by the 2004 Indian Ocean tsunami in Sri Lanka.
- Onyango [67] investigates humanitarian responses to complex emergencies.
- Cimellaro *et al.* [27] present a quantitative evaluation of disaster resilience which is implemented for evaluation of health care facilities subject to earthquakes.

Urban disaster and housing recovery

- Jung *et al.* [45] introduce some mathematical models for reconstruction planning in urban areas and design of redevelopment strategies that minimize future risk of flood and maximize net social benefit under spatial and equity constraints.
- Chang [20] presents a framework for assessing empirical patterns of urban disaster recovery through the use of statistical indicators.
- El-Anwar *et al.* [34] study how to quantify and maximize the sustainability of integrated housing recovery efforts after natural disasters.

Other activities

- Miles and Chang [61] present and operationalize a conceptual model of recovery to create a numerical model of recovery which is intended for decision support.
- Fiedrich and Burghardt [35] show how applications of agent technology can be used to support many processes throughout the phases of the disaster management cycle from mitigation and preparation to actual response and recovery.
- Semsch *et al.* [79] develop an approach for increasing the robustness of plans in multi-agent disaster, in which interactions between agents' actions and plans may arise due to simultaneous activity of the agents in a shared environment.
- Apte [7] discusses research issues and potential actions in disaster recovery.
- Chib and Komathi [25] implement information communication technologies in recovery operations, drawing attention to vulnerability reducing potential of the initiatives.
- Kaklauskas *et al.* [46] describe the development of a knowledge model for post–disaster management using multiple criteria decision making theory.
- Chao *et al.* [21] analyze the human–computer interaction of remote disaster recovery systems.

2.2.4 *Donations and funding*

Several recent papers have approached the study of the role of donations in humanitarian logistics:

- Besiou *et al.* [14] use system dynamics simulation to present studies supporting the statement that earmarked donations decrease operational efficiency in decentralized humanitarian operations.

- Pedraza Martinez and Van Wassenhove [71] use dynamic programming to find an optimal replacement policy for the International Committee of the Red Cross, showing empirically that earmarked funding affects the implementation of replacement policies in humanitarian contexts, increasing operational cost.
- Toyasaki and Wakolbinger [89] model the strategic interaction between donors and humanitarian organizations in a deterministic setting using game theory.

The importance of donations is a fundamental difference of humanitarian logistics with respect to commercial logistics; however, they have not yet been sufficiently studied by academics and there is a wide field for future research in this context.

2.2.5 *Technique classification*

Now we categorize the bibliography based on the methodology utilized for solving the formulated problems.

- Optimization techniques
  - Mathematical programming: Aftanas [2], Akkihal [3], Ang [5], Angelis *et al.* [6], Balcik and Beamon [9], Ben-Tal *et al.* [12], Blecken *et al.* [15], Bretschneider and Kimms [16], Charles [22], Chen *et al.* [23], Chiu and Zheng [26], Coffrin *et al.* [28], Coffrin *et al.* [29], Doerner *et al.* [32], Eiselt and Marianov [33], Hale and Moberg [38], Jin and Ekşioğlu [43], Jung *et al.* [45], Losada *et al.* [54], Mehlhorn [60], Nagurney *et al.* [62], Pedraza Martinez and Van Wassenhove [71], Rottkemper *et al.* [76], Van Hentenryck *et al.* [92], Xu *et al.* [97], Yi and Özdamar [99].
  - Metaheuristics: Berkoune *et al.* [13], Blecken *et al.* [15], Campbell *et al.* [18], Coffrin *et al.* [28], Huang *et al.* [42], Jung *et al.* [45], Kongsomsaksaku *et al.* [48], Maya and Sörensen [57], Nolz *et al.* [65], Nolz *et al.* [66], Saadatseresht *et al.* [77], Van Hentenryck *et al.* [92], Yi and Kumar [98].
  - Inventory control: Beamon and Kotleba [10], Beamon and Kotleba [11], Lodree and Taskin [53], Qin *et al.* [73].
  - Constraint programming: Coffrin *et al.* [28], Van Hentenryck *et al.* [92].
- Multi-criteria decision making: Aftanas [2], Crowther and Haimes [30], El-Anwar *et al.* [34], Huang *et al.* [42], Jung *et al.* [45], Kaklauskas *et al.* [46], Matisziw *et al.* [56], Nolz *et al.* [65], Orabi *et al.* [68], Orabi *et al.* [69], Ortuño *et al.* [70], Tzeng *et al.* [90], Vitoriano *et al.* [95], Vitoriano *et al.* [96], Zobel and Khansa [100].

- Simulation: Buzna *et al.* [17], Gibbons and Samaddar [37], Jotshi *et al.* [44], Kung *et al.* [49], Miles and Chang [61], Nelson *et al.* [64], Tovia [88], Uchida [91].
- Expert systems and artificial intelligence: Chao *et al.* [21], Fiedrich and Burghardt [35], Karlaftis *et al.* [47], Permann [72], Xu *et al.* [97].
- Probability and statistics: Chang [20], Cimellaro *et al.* [27], Ghesquiere and Mahul [36], Solano [81].
- Fuzzy systems: Adıvar and Mert [1], Sheu [80], Tzeng *et al.* [90].
- Dynamic systems: Besiou *et al.* [14], Buzna *et al.* [17].
- Game theory: Semsch *et al.* [79], Toyasaki and Wakolbinger [89].

2.3 Decision Aid Systems

In the last two decades the development of decision aid systems for humanitarian logistics has grown intensely. The most used systems have focused mainly on inventory control, usually leaving aside the logistics related to the supply transportation and distribution. That is the reason why the systems described below are mainly used in the phases of Preparedness and Response, due to the importance that inventory control and fleet management have in these two phases; however, depending on the particular situation, they could also be helpful in the phases of Recovery and Mitigation.

In the following, some of the most important systems are briefly described.

SUMA and LSS. In 1992, the Pan American Health Organization, together with the Regional Office of the World Health Organization under the support of different countries (principally Holland), developed the Humanitarian Supply Management System (SUMA) [85], being one of the most complete systems able to manage the information and resources when a disaster happens. This system has been used as inventory support for other tasks in employers' organizations. The full system is composed by three modules:

- Suma Central: it is the core of the system and is normally situated in the emergency operations center. The decision makers, situated at this level, collect and define every parameter of the problem such as strategic recovery and delivery places, locations for warehouses, etc.
- Field Unit: its aim is to manage the different operations in the crucial sites such as airports, seaports and places defined in the above level. All the received supplies are separated and classified in order to better tend to the needs of the affected population.

- Stock management: it registers all information concerned with the received and delivered supplies. This module balances the available inventory in a certain warehouse.

Once the strategic parameters have been defined by Suma Central, the supplies must be managed properly. For this goal, Field Unit is used to sort and label the collected supplies in the different reception sites. The classification is divided in three types of items: “Urgent! Immediate Distribution”, “Non-Urgent Distribution”, and, “Non-Priority items”. In a secondary way, the items are separated in different groups: food, medicines, etc., and then the information is sent to Suma Central. Finally, the supplies are inventoried and delivered to other warehouses or distribution hubs, arriving at the affected population under the coordination with the operations center.

As shown above, this system requires a good tool for data transmission among the three modules, which is not always possible in a place that has been affected by a disaster. This system was used up to 2005, when its successor, called Logistics Support System (LSS) [86], was implemented, taking SUMA as a support software. Agencies as PAHO and OCHA, among others, have made the project possible. LSS makes the information exchange among NGOs, donors and affected and contributed countries easier.

Like SUMA, LSS classifies and sorts the received supplies. However, the structure of the system emphasizes the treatment of the supplies being included in a database:

- Entries: the different received supplies that have arrived in a certain local point are registered in the system as well as classified and sorted.
- Deliveries: the supplies shipments are tracked by the system taking into account the initial and destination points as well as the main features of the shipment.
- Pipeline: the expected supplies appear in this module of the system.
- Request: this part of the system manages the information about those places that need specific supplies and is useful for determining how to allocate the required supplies.
- Stock basket: once the supplies have been classified in groups, this system tracks the available stocks for better managing future requirements.
- Importing/exporting: in this part, the system is able to exchange information about the supplies with other strategic places, external systems or agencies.

SUMA has been used since 1995, when it was applied in the Hurricane Louis in Caribbean Islands, and afterwards deployed in other natural disasters such as the Hurricane Mitch that hit Central America in 1998. LSS has been used since 2005, when it was applied in the Tropical Storm Stan in El Salvador. Among many others, it was also deployed in the 2005 and 2007 earthquakes that hit Pakistan and Peru, respectively, and the 2008 volcano eruptions in Ecuador. For more details on SUMA and LSS deployments, see [85, 86]. Many agencies have taken SUMA/LSS as support for humanitarian logistics, such as UN, WHO, WFP, OCHA, UNICEF, UNHCR, PAHO, CTS, Red Cross and many NGOs like ICRC, IFRC, MSF and OXFAM, among others.

HLS and HELIOS. Humanitarian Logistics Software (HLS) [82] is a centralized web based supply chain system that was developed in 2003 by the Fritz Institute in collaboration with the International Federation of the Red Cross (IFRC) and Red Crescent. It was designed basically to track supplies and financing from donation to delivery, increasing transparency of donations, speeding up the relief chain and providing more detailed information to decision makers at headquarters and in the field. The system provides an online overview of the relief pipeline and allows a quick management of resources by using web-based supplier lists and catalogues, making it possible to make orders directly online. HLS was first used in 2004 by IFRC in several relief operations, such as the Morocco earthquake, the South Asia tsunami or the Haiti hurricane. It was also used later in operations such as the 2005 earthquake in Pakistan and the 2006 earthquake and tsunami in Indonesia, among others.

Between 2007 and 2008, HLS was replaced by a more advanced software also developed by the Fritz Institute called HELIOS [83]. It is a specific humanitarian logistics decision support tool that provides organizations with online real-time data to improve supply chain management in humanitarian relief. It consists of five modules:

- The Project Management module administrates the open projects, estimating the main needs and managing requests. This is the main module, coordinating the execution of the others when needed.
- The Request Processing module manages the information concerning issued requests, such as the issuer data, required goods, pickup and delivery locations, etc.
- The Warehouse module deals with the management of stocks and it can be activated when an issue is received or a delivery is performed.
- The Mobilization module is focused on donation management, from cash to in-kind goods and services. It is used by organizations to monitor and report on donations, highly improving the information provided to donors concerning the use of their donations.

- The Procurement module is used to administrate and purchase goods, managing the corresponding quotation requests and executing orders.

The operations to be performed are automated through a web based system in order to improve the coordination between agents, but it could also be functional offline if an internet connection is not available. In 2008, World Vision International and Oxfam GB implemented HELIOS for the first time in two locations each. Later in 2009, Oxfam extended the system to 20 different countries.

SAHANA. It is a disaster management system (see [52]) that was created by the Sri Lankan IT community after the 2004 Indian Ocean earthquake and tsumani. It was conceived as an internet based system to manage disaster relief efforts during the response and recovery phases after the disaster. In fact, the word "Sahana" means "relief" in Sinhalese, one of the national languages of Sri Lanka.

The first owner of the intellectual property of Sahana was the Lanka Software Foundation making Sahana become a global open source software project supported by volunteer contributors and several national authorities. In 2009 a non-profit organization called the Sahana Software Foundation was created to continue with the development of this project, employing experts in disaster management.

Sahana is a web based automated system mainly focused on coordination and planning of humanitarian operations. From the first implementation of 2004 the software has been further improved and at the moment it contains the following tools (see [51] for more details):

- Sahana Vesuvius: led by the US National Library of Medicine, it is focused on disaster preparedness and response needs of the medical community. It is used to assist hospitals, medical facilities and jurisdictions to tie victim records with missing people reports.
- Sahana Mayon: it is a personnel and resource management tool to manage large numbers of resources. It contains disaster scenario, facility and staff management solutions.
- Sahana Eden: it is a flexible tool with several modules that can be used in the different phases of disaster management: mitigation, preparedness, response and recovery. The core modules are the following: Organization Registry (track active organizations to provide opportunities for collaboration and coordination), Project Tracking (organize projects and identify where the greatest needs are), Human Resources (manage volunteers and people involved in the project, keeping a contact list and tracking where they

are and what skills they have), Inventory (manage inventories of items and requests of warehouses, recording and automating transactions for sending and receiving shipments), Assets (manage assets such as vehicles, radio equipment or power generators, tracking their position and condition and ensuring they are used efficiently), Assessments (collect and analyze information from assessments of different organizations through the use of custom reports, graphs and maps), Scenarios & Events (plan for several scenarios according to human resources, facilities, etc.), Mapping (integrated mapping functionality providing situational awareness and supporting standard formats from other sources and GIS, such as natural hazard risks, population or weather) and Shelter Management (track information about shelters and people arriving and departing). All these modules, together with some additional optional ones, can be configured and personalized by the users to adapt them to their particular needs.

Sahana was first deployed by the Center of National Operations (CNO) at the 2005 Sri Lanka tsunami. Since then, it has been used by several organizations to provide relief assistance, such as in the 2005 Kashmir Earthquake of Pakistan (by the National Database & Registration Authority of the Government of Pakistan), the 2006 Yogjakarta Earthquake of Indonesia (by the Indonesian Relief Source) or the 2010 Floods in Venezuela (by the Government of Venezuela). The Sahana Eden tool, recently implemented, was first used for disaster response in the 2010 Haiti Earthquake, being self-deployed by the Sahana Software Foundation, also for the first time. The system has been used in many other relief operations, see [50] for more details.

HFOSS. The project HFOSS [39] is an open source software project that participates in several other smaller projects of different kinds. In particular, in the area of disaster management HFOSS has contributed to the Sahana project, already mentioned, and developed other open source tools for humanitarian relief. One of these tools is Collabbit [41], a web software for information sharing between organizations during emergencies. It has been used, for example, by the Salvation Army Emergency Disaster Services of New York, to coordinate the 2008 Thanksgiving Day Dinner program to feed more than 10,000 people or to monitor cooling centers throughout New York for people seeking refuge from the heat in the summer. Another tool developed by HFOSS is Posit [40], an Android application to be used by rescue workers to map the disaster area with a mobile phone and communicate with a central server and with other workers. It has been used, for example, by the nonprofit organization ACDI/VOCA during food and health service operations in remote rural areas in Haiti, after the 2010 earthquake.

DMIS. The Disaster Management Information System (DMIS) [84] is a web based tool developed by The International Federation of Red Cross allowing access to real time information on disaster trends, available resources and databases, in order to support an efficient disaster preparedness and response. It is only accessible to Red Cross and Red Crescent staff, delegations and Geneva headquarters.

LOGISTIX. In 2006, Doctors without Borders developed an inventory tool for medical needs so called LogistiX [58]. It focuses on medicines inventory and it is used in the normal work of the organization. It is only accesible to Doctors without Borders, and the organization gives some courses in order to teach their volunteers how to use this tool.

It is important to remark that, apart from the systems introduced before, there are also some other systems that are not specifically designed for humanitarian logistics but are also used by NGOs for humanitarian relief. In this group it is worth noting the system so called FleetWave [24], that is a web-based enterprise information system focused on fleet management that has been used, for example, by ICRC, IFRC and WFP.

Note that these systems are mainly focused on information management, making it easier to access data regarding active organizations, human resources and beneficiaries, orders already placed or to be performed, stocks and available material, maps, etc., and improving the communication between agencies and organizations involved. This information is essential to provide decision support and it is very useful in practice, significantly improving the performance of relief operations. However, to the best of our knowledge, the existing systems have not implemented any decision model, such as the ones available in the literature and commented in the previous section, to provide automated detailed inventory or distribution plans as output.

2.4 Conclusions

Recent years have seen an explosion of literature regarding disaster and emergency management. Mathematical models have become an important tool to tackle disaster and emergency humanitarian logistics, helping in the decision aid processes appearing when trying to respond to the consequences. Even though more research is needed to incorporate the additional uncertainties faced in humanitarian logistics and the inherent difficulties due to communication and coordination problems to the models, a lot of work has been done in this direction. The review presented in this work and the chapter devoted to uncertainty in humanitarian logistics for disaster management show the extent of these efforts.

There are in the literature several studies regarding future research lines is the area. Van Wassenhove and Pedraza [94] present an extensive study on Supply Chain Management best practices that are still to be adapted to humanitarian logistics. Caunhye *et al.* [19] present a study on difficulties and future research directions that can guide the development of more accurate models, insisting on the need to develop comprehensive optimization models.

Our purpose in this work has been to link the review on models with the review on decision support systems. From this work, it can be noted that humanitarian logistics research remains highly fragmented. It is not frequent to find models that combine several operations, while in the situations faced by agents many coordinated decisions have to be taken. Moreover, in general, these models are not incorporated into Decision Support Systems which can be used in practise by the involved organizations. The systems already in use are focused on information management, but do not have optimization tools in them. It is our belief that it is necessary to shorten the gap between academics and practitioners in order to be useful to the final decision makers.

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Bibliography

[1] Adıvar, B. and Mert, A. (2010). International disaster relief planning with fuzzy credibility, *Fuzzy Optim. Decis. Making* **9**, 4, pp. 413–433.

[2] Aftanas, J. M. (2007). *Optimizing the prioritization of natural disaster recovery projects*, Master's thesis, Air Force Institute of Technology, Ohio.

[3] Akkihal, A. R. (2006). *Inventory pre-positioning for humanitarian operations*, Master's thesis, Massachusetts Institute of Technology, Massachusetts.

[4] Altay, N. and Green, W. G. (2006). OR/MS research in disaster operations management, *Eur. J. Oper. Res.* **175**, 1, pp. 475–493.

[5] Ang, C. C. (2006). *Optimized recovery of damaged electrical power grids*, Master's thesis, Naval Postgraduate School, Monterey.

[6] Angelis, V. D., Mecoli, M., Nikoi, C. and Storchi, G. (2007). Multiperiod integrated routing and scheduling of World Food Programme cargo planes in Angola, *Comput. Oper. Res.* **34**, 6, pp. 1601–1615.

[7] Apte, A. (2009). Humanitarian logistics: a new field of research and action, *Found. Trends Technol. Inf. Oper. Manag.* **3**, 1, pp. 1–100.
[8] Balasubramanian, S., Mohan, T., Pineiro, R. C., Jain, R., Routray, R. R., Shah, G., Verma, A. and Voruganti, K. (2011). Methods, systems, and computer program products for disaster recovery planning, United States Patent 7945537.
[9] Balcik, B. and Beamon, B. M. (2008). Facility location in humanitarian relief, *Int. J. Logist. Res. Appl.* **11**, 2, pp. 101–121.
[10] Beamon, B. M. and Kotleba, S. A. (2006a). Inventory management support systems for emergency humanitarian relief operations in South Sudan, *Int. J. Logist. Manag.* **17**, 2, pp. 187–212.
[11] Beamon, B. M. and Kotleba, S. A. (2006b). Inventory modelling for complex emergencies in humanitarian relief operations, *Int. J. Logist. Res. Appl.* **9**, 1, pp. 1–18.
[12] Ben-Tal, A., Chung, B. D., Mandala, S. R. and Yao, T. (2011). Robust optimization for emergency logistics planning: risk mitigation in humanitarian relief supply chains, *Transp. Res. Part B* **45**, 8, pp. 1177–1189.
[13] Berkoune, D., Renaud, J., Rekik, M. and Ruiz, A. (2012). Transportation in disaster response operations, *Socio-Econ. Plan. Sci.* **46**, 1, pp. 23–32.
[14] Besiou, M., Pedraza Martinez, A. and Van Wassenhove, L. (2012). The effect of earmarked funding on fleet management for relief and development, Tech. Rep. 2012/10/TOM/ISIC, INSEAD.
[15] Blecken, A., Danne, C., Dangelmaier, W., Rottkemper, B. and Hellingrath, B. (2010). Optimal stock relocation under uncertainty in post-disaster humanitarian operations, in *Proceedings of the 43rd Hawaii International Conference on System Sciences* (Koloa, Hawaii), pp. 1–10.
[16] Bretschneider, S. and Kimms, A. (2012). Pattern-based evacuation planning for urban areas, *Eur. J. Oper. Res.* **216**, 1, pp. 57–69.
[17] Buzna, L., Peters, K., Ammoser, H., Kühnert, C. and Helbing, D. (2007). Efficient response to cascading disaster spreading, *Phys. Rev. Sect. E* **75**, 5-2, pp. 56107–56108.
[18] Campbell, A. M., Vandenbussche, D. and Hermann, W. (2008). Routing for relief efforts, *Transp. Sci.* **42**, 2, pp. 127–145.
[19] Caunhye, A., Nie, X. and Pokharel, S. (2012). Optimization models in emergency logistics: A literature review, *Socio-Econ. Plan. Sci.* **46**, pp. 4–13.
[20] Chang, S. E. (2010). Urban disaster recovery: a measurement framework and its application to the 1995 Kobe earthquake, *Disasters* **34**, 2, pp. 303–327.
[21] Chao, W., Yuanbin, L. and Xuliang, D. (2011). The research on human-computer interaction of remote disaster-recovery system, in M. Zhou and H. Tan (eds.), *Advances in Computer Science and Education Applications. Part II*, *Communications in Computer and Information Science*, Vol. 202 (Springer, Berlin Heidelberg), pp. 460–466.
[22] Charles, A. (2010). *Improving the Design and Management of Agile Supply Chains: Feedback and Application in the Context of Humanitarian Aid*, Ph.D. thesis, Université de Toulouse, Toulouse, France.
[23] Chen, A., Zhao, J. and Chen, N. (2009). A recoverability assessment model in emergency management, Tech. Rep. RTO-MP-IST-086-09, NATO Research and Technology Organisation.
[24] Chevin Fleet Solutions (2001). FleetWave, `http://www.chevinfleet.com/us/fleet_software_fleetwave_web_based_enterprise_fleet_management_solution.asp`, last access: May 7th, 2012.
[25] Chib, A. and Komathi, A. L. E. (2009). Extending the technology-community-management model to disaster recovery: Assessing vulnerability in rural Asia, in *Proceedings of the 3rd International Conference on Information and Communication Technologies and Development* (Doha, Qatar), pp. 328–336.

[26] Chiu, Y. C. and Zheng, H. (2007). Real-time mobilization decisions for multi-priority emergency response resources and evacuation groups: model formulation and solution, *Transp. Res. Part E* **43**, 6, pp. 710–736.

[27] Cimellaro, G. P., Reinhorn, A. M. and Bruneau, M. (2010). Framework for analytical quantification of disaster resilience, *Eng. Struct.* **32**, 11, pp. 3639–3649.

[28] Coffrin, C., Van Hentenryck, P. and Bent, R. (2011b). Strategic planning for power system restoration, in *Proceedings of the International Conference on Vulnerability and Risk Analysis and Management* (Hyattsville, Maryland), pp. 1–8.

[29] Coffrin, C., Van Hentenryck, P. and Bent, R. (2011c). Strategic stockpiling of power system supplies for disaster recovery, in *Power and Energy Society General Meeting, 2011 IEEE* (San Diego, California), pp. 1–8.

[30] Crowther, K. G. and Haimes, Y. Y. (2005). Application of the inoperability input-output model (IIM) for systemic risk assessment and management of interdependent infrastructures, *Syst. Eng.* **8**, 4, pp. 323–341.

[31] de Mel, S., D., M. and Woodruff, C. (2008). Mental health recovery and economic recovery after the tsunami: high-frequency longitudinal evidence from Sri Lankan small business owners, *Soc. Sci. Med.* **66**, 3, pp. 582–595.

[32] Doerner, K. F., Gutjahr, W. J. and Nolz, P. C. (2009). Multi-criteria location planning for public facilities in tsunami-prone coastal areas, *OR Spectr.* **31**, 3, pp. 651–678.

[33] Eiselt, H. A. and Marianov, V. (2012). Mobile phone tower location for survival after natural disasters, *Eur. J. Oper. Res.* **216**, 3, pp. 563–572.

[34] El-Anwar, O., El-Rayes, K. and Elnashai, A. S. (2010). Maximizing the sustainability of integrated housing recovery efforts, *J. Constr. Eng. Manag.* **136**, 7, pp. 794–802.

[35] Fiedrich, F. and Burghardt, P. (2007). Agent-based systems for disaster management, *Commun. ACM - Emerg. Response Inf. Syst.: Emerg. Trends Technol.* **50**, 3, pp. 41–42.

[36] Ghesquiere, F. and Mahul, O. (2007). Sovereign natural disaster insurance for developing countries: A paradigm shift in catastrophe risk financing, World Bank Policy Research 4345, World Bank.

[37] Gibbons, D. E. and Samaddar, S. (2009). The maximal expected coverage relocation problem for emergency vehicles, *Decis. Sci.* **40**, 2, pp. 351–371.

[38] Hale, T. and Moberg, C. R. (2005). Improving supply chain disaster preparedness: a decision process for secure site location, *Int. J. Phys. Distrib. Logist. Manag.* **35**, 3/4, pp. 195–207.

[39] HFOSS Institute (2006). HFOSS, `http://dev.hfoss.org/`, last access: February 6th, 2012.

[40] HFOSS Institute (2008). Posit, `http://posit.hfoss.org/`, last access: February 6th, 2012.

[41] HFOSS Institute (2010). Collabbit, `http://collabbit.org/about`, last access: February 6th, 2012.

[42] Huang, M., Smilowitz, K. and Balcik, B. (2012). Models for relief routing: equity, efficiency and efficacy, *Transp. Res. Part E* **48**, 1, pp. 2–18.

[43] Jin, M. and Ekşioğlu, B. (2010). Optimal routing of vehicles with communication capabilities in disasters, *Comput. Manag. Sci.* **7**, 2, pp. 121–137.

[44] Jotshi, A., Gong, Q. and Batta, R. (2009). Dispatching and routing of emergency vehicles in disaster mitigation using data fusion, *Socio-Econ. Plan. Sci.* **43**, 1, pp. 1–24.

[45] Jung, C., Johnson, M., Trick, M. and Williams, J. (2007). Mathematical models for reconstruction planning in urban areas, Tech. rep., Heinz College, Carnegie Mellon University.

[46] Kaklauskas, A., Amaratunga, D. and Haigh, R. (2009). Knowledge model for post-disaster management, *Int. J. Strateg. Prop. Manag.* **13**, 2, pp. 117–128.

[47] Karlaftis, M. G., Kepaptsoglou, K. L. and Lambropoulos, S. (2007). Fund allocation for transportation network recovery following natural disasters, *J. Urban. Plan. Dev.* **133**, 1, pp. 82–89.

[48] Kongsomsaksaku, S., Yang, C. and Chen, A. (2005). Shelter location-allocation model for flood evacuation planning, *J. East. Asia. Soc. Transp. Stud.* **6**, pp. 4237–4252.

[49] Kung, H. Y., Chen, C. H. and Ku, H. H. (2012). Designing intelligent disaster prediction models and systems for debris-flow disasters in Taiwan, *Expert Syst. Appl.* **39**, 5, pp. 5838–5856.

[50] Lanka Software Foundation (2004a). SAHANA deployments, `http://wiki.sahanafoundation.org/doku.php/deployments:start`, last access: February 6th, 2012.

[51] Lanka Software Foundation (2004b). SAHANA products, `http://sahanafoundation.org/products/`, last access: February 6th, 2012.

[52] Lanka Software Foundation (2004c). SAHANA system, `http://sahanafoundation.org/`, last access: February 6th, 2012.

[53] Lodree, E. J. and Taskin, S. (2008). An insurance risk management framework for disaster relief and supply chain disruption inventory planning, *J. Oper. Res. Soc.* **59**, 5, pp. 674–684.

[54] Losada, C., Scaparra, M. P. and O'Hanley, J. R. (2012). Optimizing system resilience: A facility protection model with recovery time, *Eur. J. Oper. Res.* **217**, 3, pp. 519 – 530.

[55] Luckey, T. S. (2009). *Key stages of disaster recovery planning for time-critical business information technology systems*, Master's thesis, University of Oregon, Oregon.

[56] Matisziw, T. C., Murray, A. T. and Grubesic, T. H. (2010). Strategic network restoration, *Netw. Spat. Econ.* **10**, pp. 345–361.

[57] Maya, P. and Sörensen, K. (2011). A GRASP metaheuristic to improve accessibility after a disaster, *Disaster Relief* **33**, 3, pp. 525–542.

[58] Médecins Sans Frontières (2006). LogistiX, `ftp://support.geneva.msf.org/permanent/LOG/SupplyChainManagement`, last access: February 6th, 2012.

[59] Mehlhorn, S., Racer, M., Ivey, S. and Lipinski, M. (2011). A single-objective recovery phase model, *Int. J. Inf. Technol. Proj. Manag.* **2**, 3, pp. 53–71.

[60] Mehlhorn, S. A. (2009). *Method for Prioritizing Highway Routes for Reconstruction After a Natural Disaster*, Ph.D. thesis, University of Memphis.

[61] Miles, S. B. and Chang, S. E. (2006). Modeling community recovery from earthquakes, *Earthq. Spectr.* **22**, pp. 439–458.

[62] Nagurney, A., Yu, M. and Qiang, Q. (2011). Supply chain network design for critical needs with outsourcing, *Pap. Reg. Sci.* **90**, 1, pp. 123–142.

[63] Natarajarathinam, M., Capar, I. and Narayanan, A. (2009). Managing supply chains in times of crisis: a review of literature and insights, *Int. J. Phys. Distrib. Logist. Manag.* **39**, 7, pp. 535–573.

[64] Nelson, S. C., Harris III, A. F. and Kravets, R. (2007). Event-driven, role-based mobility in disaster recovery networks, in *Proceedings of the Second ACM Workshop on Challenged Networks* (Montreal, Canada), pp. 27–34.

[65] Nolz, P., Doerner, K., Gutjahr, W. and Hartl, R. (2010a). A bi-objective metaheuristic for disaster relief operation planning, in C. Coello Coello, C. Dhaenens and L. Jourdan (eds.), *Advances in Multi-Objective Nature Inspired Computing*, *Studies in Computational Intelligence*, Vol. 272 (Springer, Berlin Heidelberg), pp. 167–187.

[66] Nolz, P. C., Doerner, K. F. and Hartl, R. F. (2010b). Water distribution in disaster relief, *Int. J. Phys. Distrib. Logist. Manag.* **40**, 8/9, pp. 693–708.

[67] Onyango, M. A. (2008). Humanitarian responses to complex emergencies, in Q. K. Heggenhougen (ed.), *International Encyclopedia of Public Health* (Academic Press, San Diego).

[68] Orabi, W., El-Rayes, K., Senouci, A. B. and Al-Derham, H. (2009). Optimizing postdisaster reconstruction planning for damaged transportation networks, *J. Constr. Eng. Manag.* **135**, 10, pp. 1039–1048.

[69] Orabi, W., Senouci, A. B., El-Rayes, K. and Al-Derham, H. (2010). Optimizing resource utilization during the recovery of civil infrastructure systems, *J. Manag. Eng.* **26**, 4, pp. 237–246.

[70] Ortuño, M., Tirado, G. and Vitoriano, B. (2011). A lexicographical goal programming based decision support system for logistics of Humanitarian Aid, *TOP* **19**, pp. 464–479.

[71] Pedraza Martinez, A. and Van Wassenhove, L. N. (2012). Vehicle replacement in the international committee of the red cross, *Prod. Oper. Manag.* 10.1111/j.1937-5956.2011.01316.x.

[72] Permann, M. R. (2007). Genetic algorithms for agent-based infrastructure interdependency modeling and analysis, in *Proceedings of the 2007 Spring Simulation Multiconference*, Vol. 2 (Norfolk, Virginia), pp. 169–177.

[73] Qin, J., Xing, Y., Wang, S., Wang, K. and Chaudhry, S. S. (2012). An inter-temporal resource emergency management model, *Comput. Oper. Res.* **39**, 8, pp. 1909–1918.

[74] Quarantelli, E. L. (2006). Catastrophes are different from disasters: some implications for crisis planning and managing drawn from Katrina, `http://understandingkatrina.ssrc.org/Quarantelli/`, last access: February 20th, 2012.

[75] Rose, A. (2007). Economic resilience to natural and man-made disasters: multidisciplinary origins and contextual dimensions, *Environ. Hazard.* **7**, 4, pp. 383–398.

[76] Rottkemper, B., Fischer, K. and Blecken, A. (2012). A transshipment model for distribution and inventory relocation under uncertainty in humanitarian operations, *Socio-Econ. Plan. Sci.* **46**, 1, pp. 98–109.

[77] Saadatseresht, M., Mansourian, A. and Taleai, M. (2009). Evacuation planning using multiobjective evolutionary optimization approach, *Eur. J. Oper. Res.* **198**, 1, pp. 305–314.

[78] Saleem, K., Luis, S., Deng, Y., Chen, S.-C., Hristidis, V. and Li, T. (2008). Towards a business continuity information network for rapid disaster recovery, in *Proceedings of the 2008 International Conference on Digital Government Research* (Montreal, Canada), pp. 107–116.

[79] Semsch, E., Jakob, M., Doubek, J. and Pechoucek, M. (2008). Using player models to improve robustness of HTN plans in multi-agent domains, in *Proceedings of the 27th Workshop of the UK Planning and Scheduling Special Interest Group* (Edinburgh, UK), pp. 1–7.

[80] Sheu, J. B. (2007). An emergency logistics distribution approach for quick response to urgent relief demand in disasters, *Transp. Res. Part E* **43**, 6, pp. 687–709.

[81] Solano, E. (2010). Research brief: Methods for assessing vulnerability of critical infrastructure, Tech. rep., Institute for Homeland Security Solutions.

[82] The Fritz Institute (2003). Humanitarian Logistics Software (HLS), `http://www.fritzinstitute.org/prgTech-HLS.htm`, last access: February 6th, 2012.

[83] The Fritz Institute (2007). HELIOS, `http://www.fritzinstitute.org/prgTech-HELIOS_Overview.htm`, last access: February 6th, 2012.

[84] The International Federation of Red Cross (2001). The Disaster Management Information System (DMIS), `https://www-secure.ifrc.org/DMISII/Pages/00_Home/login.aspx`, last access: February 6th, 2012.

[85] The Pan American Health Organization (1992). The Humanitarian Supply Management System (SUMA), `http://www.disaster-info.net/SUMA/english/index.htm`, last access: February 6th, 2012.

[86] The Pan American Health Organization (2005). Logistics Support System (LSS), `http://www.lssweb.net/`, last access: February 6th, 2012.

[87] Tomasini, R. and van Wassenhove, L. (2009). *Humanitarian Logistics* (Palgrave Macmillan).

[88] Tovia, F. (2007). An emergency logistics response system for natural disasters, *Int. J. Logist.: Res. Appl.* **10**, 3, pp. 173–186.

[89] Toyasaki, F. and Wakolbinger, T. (2012). Impacts of earmarked private donations for disaster fundraising, *A. Oper. Res.* 10.1007/s10479-011-1038-5.

[90] Tzeng, G. H., Cheng, H. J. and Huang, T. D. (2007). Multi-objective optimal planning for designing relief delivery systems, *Transp. Res. Part E* **43**, 6, pp. 673–686.

[91] Uchida, K. (2012). A model evaluating effect of disaster warning issuance conditions on “cry wolf syndrome” in the case of a landslide, *Eur. J. Oper. Res.* **218**, 2, pp. 530–537.

[92] Van Hentenryck, P., Bent, R. and Coffrin, C. (2010). Strategic planning for disaster recovery with stochastic last mile distribution, in H. C. Heard, I. V. Borg, N. L. Carter and C. B. Raleigh (eds.), *Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems*, *Lecture Notes in Computer Science*, Vol. 6140 (Springer, Berlin Heidelberg), pp. 318–333.

[93] Van Wassenhove, L. N. (2006). Humanitarian aid logistics: supply chain management in high gear, *J. Oper. Res. Soc.* **57**, 5, pp. 475–489.

[94] Van Wassenhove, L. N. and Pedraza, A. J. (2012). Using or to adapt supply chain management best practices to humanitarian logistics, *Intl. Trans. in Op. Res.* **19**, 1–2, pp. 307–322.

[95] Vitoriano, B., Ortuño, M. T. and Tirado, G. (2009). HADS, a goal programming-based humanitarian aid distribution system, *J. Multi-Criteria Decis. Anal.* **16**, 1-2, pp. 55–64.

[96] Vitoriano, B., Ortuño, M. T., Tirado, G. and Montero, J. (2011). A multi-criteria optimization model for humanitarian aid distribution, *J. Glob. Optim.* **51**, 2, pp. 189–208.

[97] Xu, N., Guikema, S. D., Davidson, R. A., Nozick, L. K., Çag̃nan, Z. and Vaziri, K. (2007). Optimizing scheduling of post-earthquake electric power restoration tasks, *Earthq. Eng. Struct. Dyn.* **36**, pp. 265–284.

[98] Yi, W. and Kumar, A. (2007). Ant colony optimization for disaster relief operations, *Transp. Res. Part E* **43**, 6, pp. 660–672.

[99] Yi, W. and Özdamar, L. (2007). A dynamic logistics coordination model for evacuation and support in disaster response activities, *Eur. J. Oper. Res.* **179**, pp. 1177–1193.

[100] Zobel, C. W. and Khansa, L. (2011). Characterizing multi-event disaster resilience, *Comput. Oper. Res.* 10.1016/j.cor.2011.09.024.